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DENSITY OF METEOR MATTER IN INTERPLANETARY SPACE IN RELATION TO THE POSSIBLE EXISTENCE OF A DUST CLOUD AROUND THE EARTH

(O plotnosti meteornoy materii v mezhplanetnom prostranstve v svyazi s vozmozhnost'yu sushchestvovaniya pylevogo oblaka vokrug Zemli)

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by V. G. Fesenkov.

ABSTRACT

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It is established that direct methods of determination of cosmic matter density in the interplanetary space (meteor number counts, investigation of oceanic deposits, etc.) lead to a substantially larger value than the indirect method based on the zodiacal light brightness. Even in the assumption that the particles of zodiacal light are characterized by an insignificant albedo, the resulting discrepancy is of one or two orders.

It seems as though the Earth is surrounded by a local dust cloud which adds to the cosmic matter penetrating the upper atmosphere layers. The counterglow phenomenon is possibly due to such cloud, that forms a sort of dust tail oriented in the direction opposite to the Sun.

COVER TO COVER TRANSLATION.

In order to judge the density of cosmic dust matter in the interplanetary space, and for a better comparison of the results obtained, it is appropriate to start from data of different character.

Opic contributed a method of qualitative meteor number count, when these are visible to the naked eye, and extended it also to telescopic meteors. However, a substantial difficulty then arises when passing from the observed brightness to the corresponding mass. According to F. Watson's summary [1], the total mass of meteor matter trapped by the Earth's atmosphere may be estimated as being $4.6 - 0.36 \cdot 10^6$ m per year in the aggregate. Recently Whipple [2] obtained through data by Millman $0.7 \cdot 10^6$ m per annum for that magnitude.

Another means of determining the magnitude of cosmic matter trapped by the Earth consists in its direct determination among atmospheric aerosols in a given volume of air. Such aerosol collecting is for example organized in Hawai islands by H. Pettersson [3].

Nickel content constitutes the criterion of the cosmic nature of aerosols; it is related to rare elements of the earth's crust. Admitting that the meteor matter contains 2.5 percent of Ni, and in order to obtain the corresponding weight of the cosmic matter, it is obviously necessary, when determining the quantity of that element in collected aerosol test samples, to multiply their weight by 40. This method provides a rather uncertain result, for it compels us to make assumptions concerning the rate of cosmic aerosols' fall out on the ground, which is dependent upon their dimensions and the state of the atmosphere also, and it cannot be accurately computed in general. If however we assume, as does Petterson, that these aerosols precipitate at the same rate as did the volcanic dust of Krakatoa eruption in 1883, we may find on the basis of his measurements, that the Earth receives nearly $14 \cdot 10^6$ m each year, which however is rather vague.

The magnitude of meteor dust precipitation may be estimated mo e reliably by its deposits in ocean depths, although, as this was already proved by data of Challenger expedition in 1876, hard deep-water sediments increase only by 1 to 2 mm per thousand years.

Attempts to isolate directly the cosmic matter in the form of tiny magnetic balls, for example, with the aid of electromagnetic screens and other gadgets, do not lead to satisfactory results, since not only the tiniest magnetic balls, but also those of silicate nature, containing minimal amounts of iron-nickel, are then being lost. Even in the given case more reliable results may be obtained by way of a corresponding chemical analysis and separation of nickel. In 1950, for example, Petterson and Rotshie [4] established a 0.044% nickel content in 77 samples of sediments from the Pacific Ocean, while continental magmatic rocks contain only 0.008% of that element. Ascribing this difference to cosmic matter admixture, one may determine its quantity with a comparatively greater reliability than by way of magnetic ball collecting, and thus derive the yearly fall out on earth. The magnitude then obtained is of the same order as that resulting from direct meteor observation, i.e. of the order of $5 \cdot 10^6$ m.p.a.

An assumption may be made that this matter enters into the composition of sufficiently decomposed meteor streams, and generally moves around the Sun along various elliptical orbits, similarly to the motion of periodical comets, having mainly a straight motion direction. The effective radius of the cross section surface of the Earth relatively to that matter, trapped by it, is being determined by the distance d from the center of the Earth to the asymptote of the hyperbola along which the meteor particle moves, while the distance of the perihelion of such an hyperbola must correspond to the altitude of atmospheric layers, where meteor capture takes place, i.e. at about 100 to 150 km. above the terrestrial surface.

As is easy to see

$$d = \sqrt{ap},$$

where a is the true axis of the hyperbola, p is its parameter.

Taking into account that

$$a = \frac{kM}{v_\infty^2}$$

M being the mass of the Earth, v_∞ — the meteor particle's relative velocity at infinity, k — the gravitational constant, we find that

$$kM = 4 \cdot 10^{20}.$$

Taking into account that

$$\sqrt{kMp} = R\left[2kM\left(\frac{1}{R} + \frac{1}{2a}\right)\right]^{1/2},$$

we find, that

$$\frac{d}{R} = \left(2\frac{a}{R} + 1\right)^{1/2},$$

where R is the radius of the terrestrial globe, increased by the altitude of the trapping atmosphere layer

$$R = 6.5 \cdot 10^8 \text{ cm}.$$

If the Earth moves along its orbit amid an immobile particle swarm, in that case

$$v_\infty = 30 \text{ km/sec} = 3 \cdot 10^6 \text{ cm/sec}$$

and

$$\frac{d}{R} = 1{,}066.$$

But if we postulate that $v_\infty = 5$ km/sec, then

$$\frac{d}{R} = 2{,}433.$$

The volume of space being exhausted by the moving Earth during a year is

$$V = 2\pi^2 r d^2,$$

where r is the radius of the terrestrial orbit.

The mean density of substance (matter) in the volume unit will be

$$\delta = \frac{m}{V} .$$

Assuming that the trapped mass constitutes $5 \cdot 10^{12}$ g, as was earlier admitted, we find that

$$\delta = 3{,}504 \cdot 10^{-20} \text{ or } 0.674 \cdot 10^{-20} \text{ cm}^{-3}$$

depending on whether the boundary velocity v_∞ is equal to 30 km/s or to 5 km/sec.

For effective particle dimensions, 10μ as an average, their number per cubic kilometer will be in both cases respectively

$$N = 2.79 \cdot 10^3 \text{ and } 0.535 \cdot 10^3 \text{ km}^{-3}.$$

The extinction produced by such particles results negligibly small, even within the range of one astronomical unit. Indeed, the optical thickness τ, determined according to the expression

$$e^{-\tau} = 1 - N\pi\delta^2 r,$$

respectively results to be $4.2 \cdot 10^{-5}$ and $0.803 \cdot 10^{-5}$.

The above-presented computation seems to be sufficiently simplified, yet providing at the same time a valid order for the magnitude searched for. A strict solution of the problem, accounting for orbit distribution by dimensions, eccentricities and inclinations, is impossible without introducing complementary hypotheses, and it cannot be justified on the ground of the unreliability of the initial data.

Another method of density determination of interplanetary matter may be based upon the observable brightness of the Zodiacal light. The problem consists in the linking of the observed brightness of the Zodiacal light with its optical thickness, and in relating the latter with the corresponding mass of the scattering matter.

The optical thickness τ is linked with the scattering capacity of the medium by the expression

$$\tau = \tau_a + 2\pi\mu \int_0^{\pi} f(\vartheta) \sin\vartheta \, d\vartheta,$$

where the first term characterizes the pure absorption, the effect of which is in no way felt in the observed brightness, and $\mu f(\vartheta)$ is the value of the scattering indicatrix in the direction of the angle ϑ between the incident and the diffused rays.
The brightness of Zodiacal light may be represented by the following expression

$$J = L \int_0^{\infty} \frac{\mu f(\vartheta) \, d\Delta}{r^2},$$

where Δ, r respectively are the distances from the Earth and from the Sun of the examined element of volume, L is the luminous flux from the Sun per solid angle unit. On the basis of the condition of stationary state, one may admit that the density of the matter in the ecliptic plane varies inversely proportionally to the distance from the Sun. Such admission provides, as is well known, the brightness distribution in the Zodiacal light as a function of angular distance from the Sun l, which agrees sufficiently well with the reality. In such case, we have

$$J = J_0 R^3 \mu_0 \int_0^{\infty} \frac{f(\vartheta) \, d\Delta}{r^3}$$

where J_0 is the illumination from the Sun at the distance of one astronomical unit, or

$$J = J_0 \frac{R\mu_0}{\sin^2 l} \int_l^{\pi} f(\vartheta) \sin\vartheta \, d\vartheta,$$

where l is the angular distance from the Sun of the examined point of the sky.

Assuming

$$\tau_0 = \tau_{a,0} + 2\pi\mu_0 \int_0^{\pi} f(\vartheta) \sin\vartheta \, d\vartheta,$$

we find that

$$(\tau_0 - \tau_{a,0}) R = \frac{2\pi \sin^2 l}{K} \frac{J}{J_0},$$

where the coefficient K stands for the integral relation:

$$K = \frac{\int_l^{\pi} f(\vartheta) \sin\vartheta \, d\vartheta}{\int_0^{\pi} f(\vartheta) \sin\vartheta \, d\vartheta}.$$

This relation results to be very little dependent on the character of the scattering indicatrix, and it may thus be computed with a sufficient precision. Even a simple spherical indicatrix of scattering provides, as it seems to be the case, a sufficiently proper magnitude to this relation, for sufficiently great angles ϑ at the very least.

Indeed, assuming for instance,

$$f(\vartheta) = 1 + \alpha\cos\vartheta + \beta\cos^2\vartheta + \gamma\cos^3\vartheta,$$

we find

$$K = \frac{1 + \cos\vartheta - \frac{\alpha}{2}\sin^2\vartheta + \frac{\beta}{3}(1 + \cos^3\vartheta) - \frac{\gamma}{4}(1 - \cos^4\vartheta)}{2\left(1 + \frac{\beta}{3}\right)}$$

With $\alpha = 0.049$; $\beta = 1.093$; $\gamma = 0.0704$, which corresponds for terrestrial aerosols to a wavelength of about 476 mμ, we obtain values of K for various angles ϑ in the first line of the Table under the heading (a). Similar computations may be made for a form of the scattering indicatrix derived directly from the observation of the daylight sky:

$$f(\vartheta) = 1 + 5\,(e^{-3\vartheta} - 0.009) + 0.55\cos^2\vartheta,$$

which is distinguished by a greater dissymmetry. The respective values of K are presented in the same Table under the heading (b).

ϑ	0°	20°	40°	60°	80°	90°	100°	110°	130°	150°	160°	180°
$K(a)$	1.00	0.93	0.79	0.63	0.48	0.42	0.36	0.30	0.18	0.06	0.02	0.00
$K(b)$	1.00	0.92	0.77	0.62	0.48	0.41	0.35	0.29	0.17	0.06.	0.02	0.00

If we postulate that the brightness of Zodiacal light at angular distance from the Sun equals about to 25 fifth-magnitude stars per square degree, which should be close to the reality, and the illumination due to the Sun in the same units is

$$J_0 = 2.512^{26.8+5} = 10^{12.72},$$

then

$$(\tau_0 - \tau_{a,0})\, R = \frac{2\pi}{0.73} \cdot \frac{1}{2} \cdot \frac{25}{10^{12.72}} \left(\frac{180}{\pi}\right)^2 = 6.73 \cdot 10^{-8}.$$

This expression represents the optical thickness only corresponding to light scattering by the interplanetary medium with a density at the distance from the Earth from the Sun, and calculated for one astronomical unit.

The problem amounts to transiting to the corresponding mass.

Let us now examine, for the sake of comparison, an interstellar dust medium, whose density is near $5 \cdot 10^{-26}$ g/cm^3, which corresponds in all to a quantity of $1.55 \cdot 10^{-4}$ g in a column of 1 cm^2 cross section, and 1000 ps in length, thus in $3.1 \cdot 10^{21}$ cm. At such distance the absorption of light produced is as an average equal to one stellar magnitude, i.e. it corresponds to the optical thickness of $\tau = 0.922$.

Comparing it the properties of the interplanetary medium, we have by way of analogy, that in case of pure scattering, the quantity of matter per astronomical unit would only constitute $11.3 \cdot 10^{-12}$ g for a medium's density of $0.753 \cdot 10^{-2}$ g/cm^3. Hence, for the total mass of cosmic dust matter in a spherical volume inside the terrestrial orbit, we find, accounting for the density variation, inversely proportional to the distance,

$$M = 4\pi m_0 r_0 \int_0^{r_0} r dr = 1.59 \cdot 10^{16} \text{ g},$$

which is equivalent to the mass of an asteroid with a 2 km diameter. If we consider the "ellipsoidicity" of surfaces of similar density, the indicated magnitude must be multiplied by the polar to equatorial axis ratio. The so-obtained magnitude obviously represents only the lower limit of the mass, since the mean dimension of interplanetary dust particles is only near 0.1μ. Such dust, producing a great extinction, must be pushed beyond the solar system by the pressure of Sun's luminous radiation.

If we postulate, for example, that the particle radius σ is equal to 10μ, we shall obtain from the expression for the optical thickness $R\tau_0$:

$$e^{-R\tau_0} = (1 - \pi\sigma^2)^n,$$

that the number of particles

$$n = \frac{6.73 \cdot 10^2}{\pi},$$

whence at a density 3 we find for the mass in 1 cm^3, at distances from the Earth to the Sun $1.8 \cdot 10^{-23}$ g/cm^3, or, for the total mass within the bounds of the terrestrial orbit

$$M = 3.8 \cdot 10^{17} g,$$

which corresponds to the equivalent mass of an asteroid of 6.12 km in diameter. However, the corresponding computation must be effected for the aggregate of particles of various dimensions. The direct observations of meteors, and the theoretical considerations too, indicate that the distribution of particles by dimensions may be represented by the expression:

$$\frac{dN}{dr} = \alpha r^{-4}.$$

Besides, it may be admitted, that their scattering capacity is

proportional to γ^{β}, while for particles with a radius greater than 0.5μ, the exponent β is practically equal to two.

The variation of β in the function $\underline{r}$ may be approximately represented in the following manner:

$r(\mu)$	0.1	0.2	0.3	0.4	0.5	0.6	1.0
β	5.9	4.2	3.15	2.5	2.0	2.0	2.0

Thus, in the given case

$$\tau = \alpha\pi \int_0^{\infty} r^{\beta} r^{-4}\, dr,$$

Inasmuch as for pure scattering

$$\tau = \frac{6.73}{1.5} \cdot 10^{-21},$$

we find that

$$\alpha = 4.46 \cdot 10^{-25}.$$

If the upper limit of particles' dimensions is taken as 1 cm, and the lower limit r_0, at which particles may remain within the limits of the solar system, is taken as $0.1\mu = 10^{-5}$ cm, we find from the expression

$$m = -\frac{4}{3}\pi\rho\alpha \ln r_0,$$

admitting the density $\rho = 3$, we find that

$$m = 7.62 \cdot 10^{-23}.$$

Hence, the total mass of the dust matter within the bounds of the terrestrial orbit will be

$$M = 1.61 \cdot 10^{18} g,$$

which corresponds to an asteroid with a 10 km diameter.

These computations were made in the assumption that the pure scattering is absent, i.e. that the albedo of reflecting or scattering particles is equal to the unity.

In the presence of a significant amount of pure absorption, the value of spatial density of interplanetary matter may be even increased by a whole order, and reach 10^{-21} g/cm^3. Nevertheless, there remains a certain gap with the determinations carried out on the basis of direct calculation of the quantity of meteoric matter penetrating the upper layers of the terrestrial atmosphere. These determinations were based on the assumption that the cosmic matter, entering the terrestrial atmosphere, is equally spread along the total extent of the terrestrial orbit. It results, under the circumstances, that the brightness of Zodiacal light ought to be considerably greater than that observed in reality.

Thus, a conclusion must be made, that the cosmic matter not only reaches us from interplanetary space as a whole, but also from the closest terrestrial neighborhood. Therefore, the Earth must be surrounded by a peculiar dust cloud. Its dimensions must be quite small in comparison with the solar system, and it therefore cannot be revealed in the Zodiacal light phenomenon. If we conceive that particles of that cloud are progressively pushed aside, gradually being destroyed under the effect of hard solar radiations [5], and oriented toward the side opposite to the Sun, creating a peculiar dust tail near our Earth, the known counterglow phenomenon may possibly also be explained in the same fashion.

**** E N D ****

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Translated by ANDRE L. BRICHANT
for NASA HEADQUARTERS, Washington,
4 February 1962.

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